WÅMDII

The Wide Angle Michelson Doppler Imaging Interferometer

NASA/National Research
Council of
Canada/WAMDII
*Science Team*

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I. Introduction

In comparison to the vast knowledge of global factors such as wind speed, pressure, and temperature that affect weather in the lower atmosphere, little is known about upper atmospheric weather dynamics. As part of an effort to learn more about the upper atmosphere and how it is linked to the weather we experience each day, the National Aeronautics and Space Administration (NASA) and the National Research Council of Canada (NRCC) are jointly sponsoring the Wide Angle Michelson Doppler Imaging Interferometer (WAMDII) Mission. WAMDII will measure temperature and wind speed in the upper atmosphere. This international cooperative Shuttle mission is one in a continuing series of Attached Shuttle Payloads. WAMDII is tentatively scheduled for launch in the early 1990's.

In addition to providing information on the upper atmosphere, the wind-speed and temperature readings WAMDII takes will also be highly useful in developing and updating computer-simulated models of the upper atmosphere. These models are used in the design and testing of equipment and software for Shuttles, satellites, and re-entry vehicles.

WAMDII data will contribute to the field of comparative planetology as well. In making its wind-speed and temperature measurements, WAMDII examines the Earth's airglow, a faint photochemical luminescence caused by the influx of solar ultraviolet energy into the upper atmosphere. During periods of high solar flare activity, the amount of this ultraviolet energy entering the Earth's upper atmosphere increases. This increase may effect airglow emissions.

WAMDII Payload in Orbiter Bay
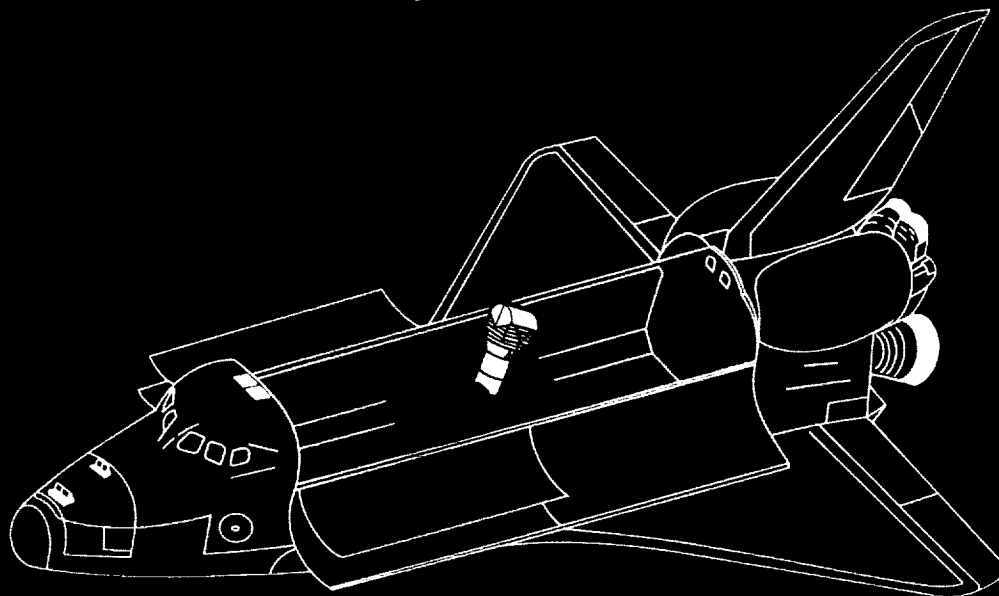
The airglow phenomena has also been known to occur in the atmospheres of other planets. By obtaining more information on the Earth's airglow, it may be possible to further our understanding of how this phenomenon works in the atmospheres of other planets. This would make it possible, for instance, to track the impact of a solar flare as it travelled through the solar system.

The WAMDII concept was developed at Canada's York University in the Center for Research in Experimental Space Science which now works with the recently formed Institute for Space and Terrestrial Sciences. The Universities of Saskatchewan, Calgary, and Western Ontario assisted in this development along with the Herzberg Institute of Astrophysics at NRCC in Ottawa. SED Systems in Saskatoon has built the proof-of-concept instrument under the project management of NRCC.

NASA's Goddard Space Flight Center (GSFC) in Greenbelt, Maryland is responsible for the mission. WAMDII will conduct its observations attached to NASA's Space Shuttle. To carry out its work, the instrument will be put in NASA's Two-Axis Pointing System (TAPS) and the TAPS Support Structure (TSS) which straddles the payload bay. Both the TAPS and TSS are being developed by GSFC.

An avionics system, developed at GSFC, is also mounted on the TAPS Support Structure. This system will enable ground controllers to communicate with and command and control WAMDII.

WAMDII — Two-Axis Pointing System — TAPS Support Structure
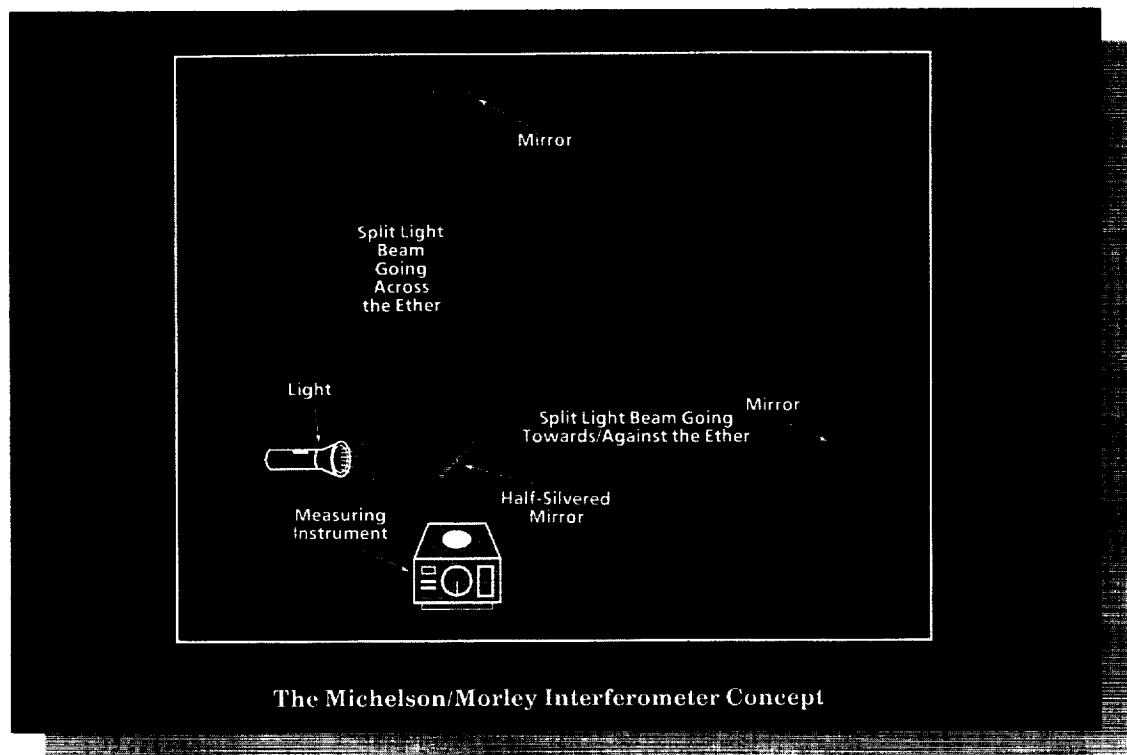
WAMDII Payload Space Shuttle Configuration
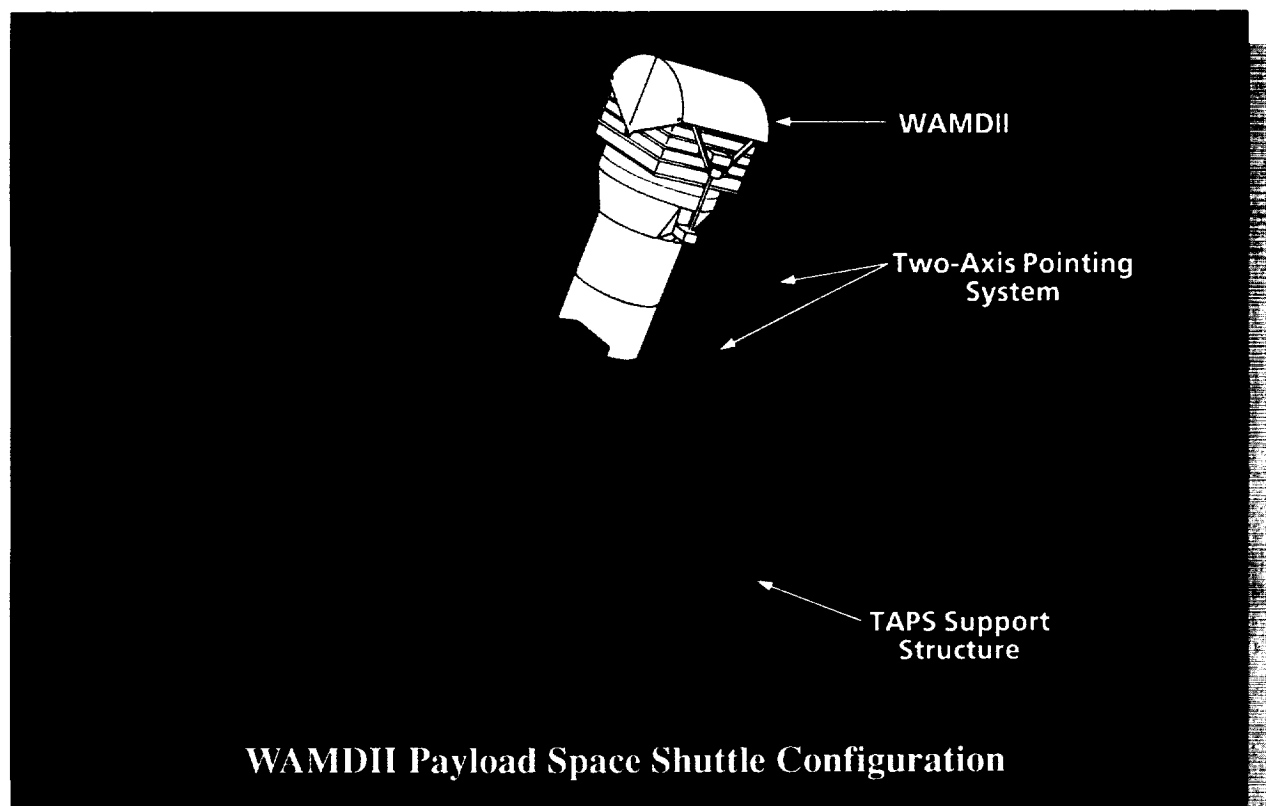
II. Background

Physicists Albert Michelson and Edward Morley developed an interferometer in the late 1880's to measure the speed at which the Earth moved through space. Popular thought at the time of Michelson and Morley was that light existed in the form of waves that required an invisible medium in which to travel. This medium was known as "ether." The interferometer used in the Michelson-Morley experiment was intended to detect the speed of the Earth as it moved through this medium and, thus by inference, the presence of the ether.

Michelson and Morley reasoned that the movement of the Earth through the ether would cause an ether breeze. They anticipated that a light beam sent upstream against the ether breeze and then downstream with it would take longer to return to its starting point than a light beam sent back and forth across the breeze. (Pilots have found that it takes longer to fly a given distance if one leg of the trip is against a head wind — even though the return leg is with a tail wind — than it takes to fly the same distance across the same wind.)

To verify the existence of the ether, Michelson and Morley built an interferometer to split a beam of light and send the component beams in different directions; one would travel toward and then against the ether breeze, the other would go across it. The beams would then reflect off two mirrors and recombine at the same splitter, producing an interference pattern, a visual representation of the light wave (see photo on page 15). The recombination of split beams is extremely sensitive to wavelength shifts; changes in the interferogram represent changes in wavelength. The time difference between the two paths the beams followed would be too small to measure directly. By observing the interference pattern created by the recombined beams, however, one could detect a particular but unknown time delay which could help derive a velocity measurement. By rotating the instrument 90°, the "toward-against" and "across" paths were reversed, so a change in the interference pattern was expected to occur. The Michelson-Morley experiment showed that there was no change in interference patterns when the instrument was rotated; not the slightest difference in velocity could be noticed between the two beams.

Michelson and Morley believed their results were correct even though they could not explain them and had failed to predict the existence of the ether. Their work, however, was not in vain. The results of their experiment helped provide the foundation for Einstein's theory of relativity in which both the ideas of ether and of absolute position were abandoned. It was also found some seventy years later that interferometry was an ideal process to use for measuring atmospheric temperature and wind speed. WAMDII is a modern application of this classic scientific measurement technique.

Mirror

Split Light
Beam
Going
Across
the Ether

Light

Split Light Beam Going
Towards/Against the Ether

Mirror

Measuring
Instrument

Half-Silvered
Mirror

The Michelson/Morley Interferometer Concept

Drawing and excerpt pp. 130-131 from The Dancing Wu-Li Masters by Gary Zukav.
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COLOR PHOTOGRAPH

III. Science Overview
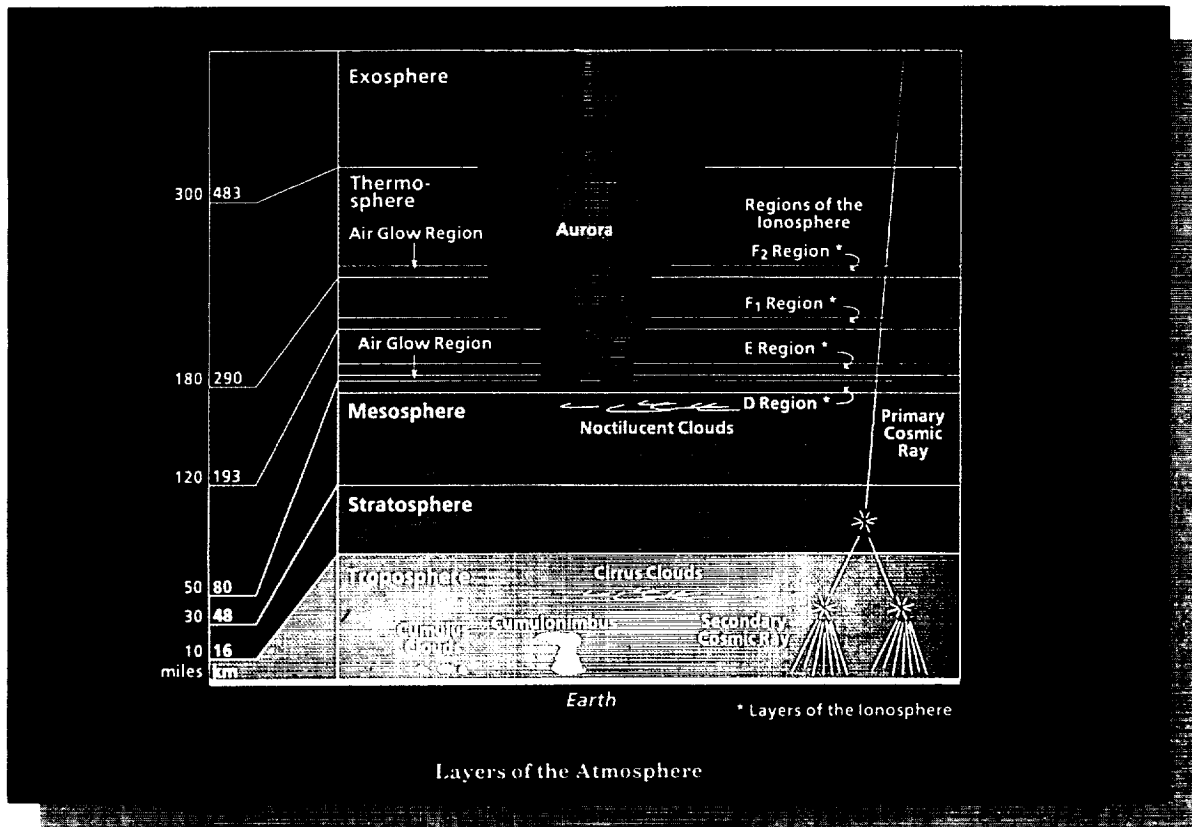
• *The Sun-Earth Weather Link*

The origins of the Earth's weather are found not just in the immediate atmosphere but in a complex chain of interactions between the Earth and sun. The sun, although primarily a life-giving force for the Earth, can also be a damaging one. Protecting the Earth by lessening the potentially harmful effects of the sun are several atmospheric layers. Each layer carries out a unique function. Each helps shape the Earth's weather.

Scientists view the Earth's atmosphere as having an upper and a lower component. The lower atmosphere, or troposphere, extends from six to ten miles (10 to 16 km) above the Earth's surface. In this region, the home of large-scale wind systems, storms, and clouds, our everyday weather occurs. The upper atmosphere extends from approximately 10 to 300 miles (16 to 500 km) above the Earth's surface and comprises several different regions: the stratosphere, mesosphere, thermosphere, and ionosphere.

• *The Upper Atmosphere*

The meteorology of the upper atmosphere is now beginning to be actively investigated. A few upper atmospheric wind speed and temperature measurements have been made from both the ground and satellites. The space-based measurements WAMDII takes will greatly extend our knowledge of this region.

An upper atmospheric phenomenon crucial to life in the lower atmosphere is the transformation of ultraviolet energy from the sun into the thermal energy which heats the Earth. In order to understand the complex mechanisms behind this energy transformation, scientists need detailed upper atmospheric temperature and wind velocity readings. Much of this type of data currently available represents or is derived from averages of measurements made sparsely over long periods of time. However, great variances occur between these averages and actual (instantaneous) values. WAMDII data will provide the detailed specific measurements necessary for better understanding the crucial ultraviolet-to-thermal energy transfer mechanism.

Exosphere		
300 483	**Thermo-sphere** / Air Glow Region	**Aurora** / Regions of the Ionosphere / F_2 Region *
		F_1 Region *
180 290	Air Glow Region	E Region *
	Mesosphere / Noctilucent Clouds	D Region * / Primary Cosmic Ray
120 193	**Stratosphere**	
50 80 / 30 48 / 10 16 / miles km	Troposphere / Cumulonimbus / Cumulus	Cirrus Clouds / Secondary Cosmic Ray

Earth   * Layers of the Ionosphere

Layers of the Atmosphere

As ultraviolet energy is transformed into thermal energy in the upper atmosphere, it is also absorbed. Because of this absorption or screening process, a solar spectrum relatively low in highly energetic and potentially damaging ultraviolet radiation reaches the Earth. This screening occurs in phases. In travelling Earthward from the sun, a significant amount of the shortest wavelengths of ultraviolet radiation is absorbed in the thermosphere. Some, at longer wavelengths, is not screened until it reaches the stratosphere and troposphere. Very little reaches the Earth's surface. WAMDII data will help scientists understand the unique role each upper atmospheric region plays in this screening process.

Stratosphere

The region of the upper atmosphere closest to the Earth is the stratosphere, which extends from approximately 10 to 30 miles (16-48 km) above the Earth. The absorption of ultraviolet light in this region creates the ozone layer which surrounds and protects the Earth from the harmful effects of the sun. Temperatures in this buffer region are very similar to those at the Earth's surface, approximately 32 degrees Farenheit (zero degrees Celsius). Despite temperature similarities, the stratosphere's complex meteorology is not easily related to that of the troposphere. Fortunately, high-altitude aircraft and balloons make the stratosphere accessible for study.

Mesosphere

Since it cannot be reached by high-altitude aircraft or the lowest flying spacecraft, the mesosphere, at approximately 30 to 50 miles (50 to 80 km) overhead, is the least understood region in the upper atmosphere. Yet, it provides an important link between the stratosphere and the thermosphere that requires further explanation. Internal atmospheric gravity waves generated near the ground (further discussed on page 10) are thought to break in this region. Because of its proximity to the ozone layer, meteorological information concerning the mesosphere can be of use to scientists researching the ozone depletion our planet now faces. WAMDII will expand the base of the much-needed mesospheric data.
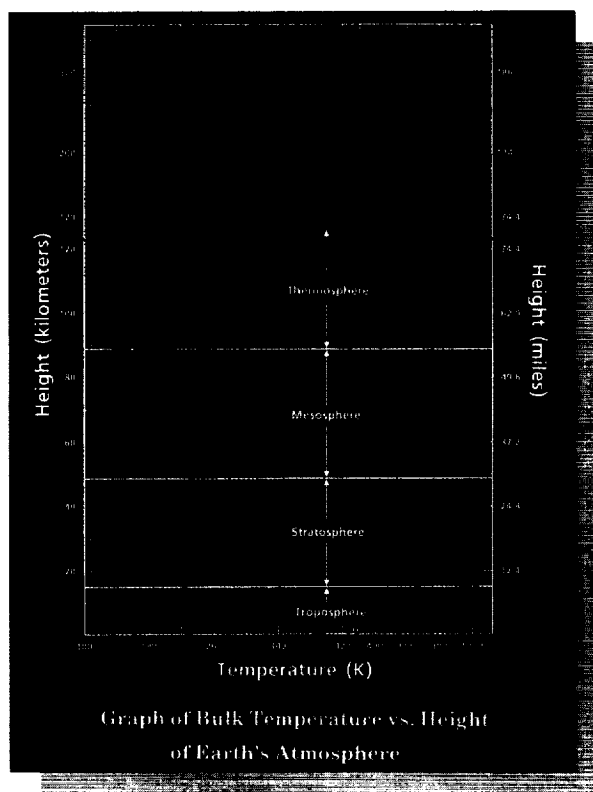
Thermosphere

In the thermosphere, approximately 50 and 300 miles (85 and 500 km) above the Earth, the atmosphere has thinned to less than one millionth of the density of the air we breathe. It is in this region that WAMDII takes most of its wind-speed and temperature readings. Little is known about the weather dynamics of the thermosphere, one of the largest links in the sun-Earth weather chain. Thermospheric air is so thin that it is impossible to obtain accurate meteorological measurements by methods used in the lower atmosphere. Upper atmospheric temperature readings are made, instead, by measuring the average speed of randomly moving molecules or atoms in airglow emissions, layers of colored light in the upper atmosphere.

Wind measurements are made by observing the average velocity of the organized molecular and atmospheric motions.

Ionosphere

Solar energy streaming into the thermosphere splits the oxygen molecules present into atoms. The atoms are then further split into electrically charged particles called ions. Created when an atom or molecule becomes charged as a result of losing the electrons in its outer shell, the ions form a series of electrically conductive layers high above the Earth. Known as the ionosphere, these layers permeate both the upper mesosphere and the thermosphere. They also act as tiny reflectors or absorbers (depending on their level of ionization) capable of bending radio waves sent from Earth, thus making long-distance radio communication possible. The sun-Earth weather link becomes especially apparent in the ionosphere during solar flares when long distance radio communications may be blacked out for hours because of the disruption of these layers of ionized particles. Ion winds in these regions are driven by electric fields formed in the sun-Earth interaction, and their influence on the circulation of the neutral gas in the ionosphere as well as Earth-based electrical systems is currently being investigated. WAMDII will make a global exploration of the relationships between the neutral and ionized winds.

From: Solar Terrestrial Physics: Principles and Theoretical Foundations, R.L. Carovillano and J.M. Forbes, editors, (c) 1983, D. Reidel Publishing Co.
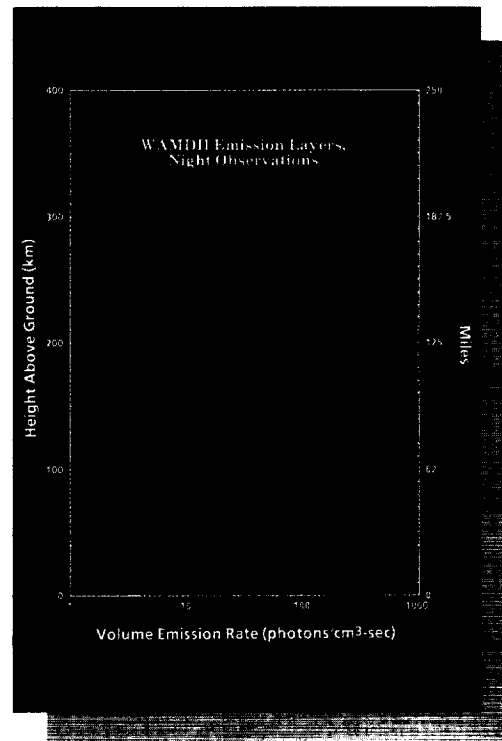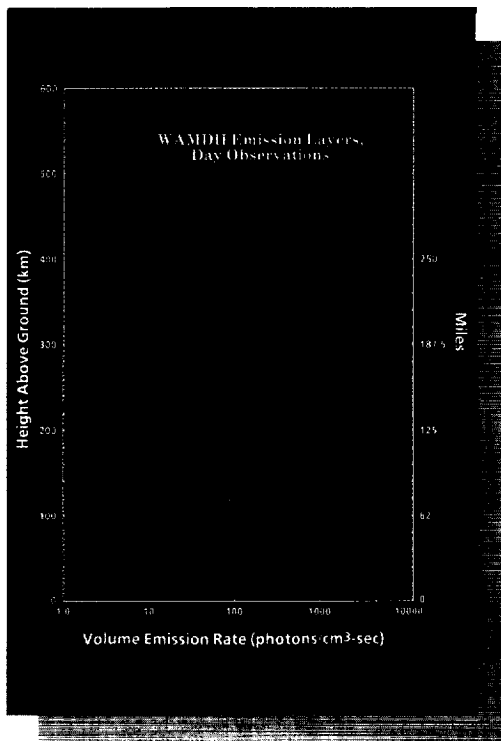
6

• *Airglow*

The amount of ultraviolet light blocked by the thermosphere is much less than that contained in the visible light which reaches the Earth's surface and keeps us warm. This ultraviolet light, however, has a profound impact on the thermosphere. When it splits many of the sparse oxygen molecules present into their atomic components, many of the atoms are left in an excited state. For the atoms to recombine into molecules, the excited atom must lose its extra energy and return to the neutral state. In reaching this state, the extra energy of the excited atom is emitted as a photon of light known as airglow. WAMDII obtains its data by observing the bulk movement of airglow emissions and the random movement of molecules or atoms within these emissions.

The various layers of the airglow differ in color depending on the reaction of the ultraviolet light with upper atmospheric atoms and molecules in the region. The frequencies of the light waves of these airglow emissions are well known and provide an ideal means for measuring upper atmospheric wind speed and temperature. The graphs of airglow emissions show the phenomena WAMDII expects to observe in obtaining its data, the color (if any) of the emission, and the emission altitude.

Airglow and Aurora Photo taken on Spacelab 3, April 1985, courtesy of NASA/Don Lind

WAMDII Emission Layers, Day Observations

Height Above Ground (km)

Miles

Volume Emission Rate (photons/cm3-sec)

WAMDII Emission Layers, Night Observations

Height Above Ground (km)

Miles

Volume Emission Rate (photons/cm3-sec)

O₂ Molecular oxygen (764 nm): The emission graph shows that the airglow visible at the lowest altitude range, the O_2 emission, is of a whole oxygen molecule. Oxygen gives off a glow of color in the near infrared range which is invisible to the unaided human eye.

O Atomic oxygen: At higher altitudes, where more ultraviolet energy is present, oxygen molecules are split into their atomic components. Two atomic oxygen emissions are visible: one green (558 nm) and one red (630 nm).

O^+ Ionized oxygen (732 nm): In the highest regions of the thermosphere, ultraviolet energy acts on oxygen atoms by splitting them even further. This causes them to lose electrons in their outer shells. Since these electrons are charged negatively, their absence makes the oxygen atom become positively charged. Atoms in this state are called ions. Their emissions are also in the infrared range.

OH Hydroxl (734 nm): This emission occurs at the top of the mesosphere and is caused by the reaction of atomic hydrogen with ozone. It provides information on the lowest altitude WAMDII observes at night, the area most subject to the activity of internal atmospheric gravity waves (further discussed on page 10). The following chart shows the expected radiance of the different airglow emissions.

Airglow Spectrum Observed by WAMDII

Expected Radiance (Kilorayleighs)

Wavelength (nm)
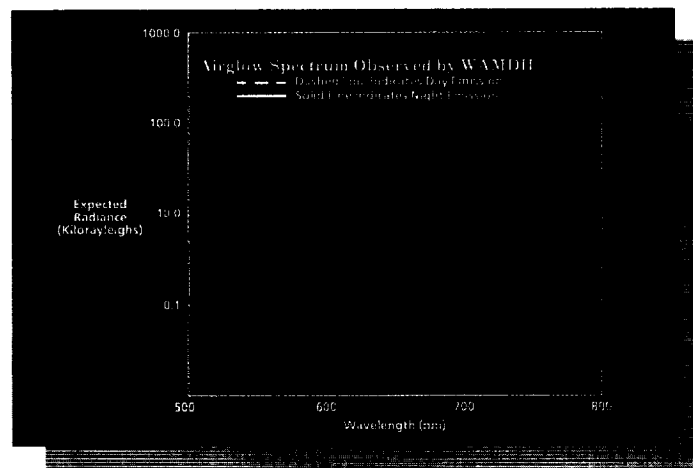
Kilorayleighs measure light intensity. A radiance of one kilorayleigh means that one billion photons per second are being emitted from a column one square centimeter in area, aligned along the viewing direction.

• *Aurora*

The sun affects the thermosphere not only through its ultraviolet light but also through the solar wind. Emitted from the sun at 240 miles per second (400 km/sec.), the solar wind is a flow of plasma, a high-temperature ionized gas composed of electrons and positive ions. These opposite charges exist in such equal numbers that the gaseous medium is essentially electrically neutral. While many of the solar wind particles are diverted around the upper atmosphere by the magnetosphere (a magnetic field emanating from the Earth's metallic core), some penetrate the magnetosphere and cause beams of electrons to flow along the Earth's magnetic field lines from the magnetosphere to the high-latitude atmosphere. When the electrons of this plasma strike the upper atmosphere, they produce light which results in the brilliant color display seen in the northern sky as the aurora borealis or northern lights and in the southern sky as the aurora australis. WAMDII can obtain wind speed and temperature measurements by observing aurora as well as airglow emissions.

One of the remaining mysteries of the aurora is whether it is linked to weather effects at the Earth's surface. Statistically, it is found that weather effects such as drought are correlated with the solar wind, and hence the aurora. A mechanism explaining this link has yet to be found. By exploring the linkages between the different atmospheric layers, WAMDII will contribute to the solution of this mystery.

Auroral Bands Visible in Alaska, Photo by Lee Snyder

• Internal Atmospheric Gravity Waves

In addition to providing excellent coverage of the global upper atmospheric wind circulation, WAMDII will provide information on smaller scale winds and internal atmospheric gravity waves. These waves are generated near the Earth and propagate upwards into the upper atmosphere. They cause the entire atmosphere to oscillate up and down, changing the density at any one point. Because of this, they can influence any wind speed or temperature readings made in a specific area. They also transport energy from one place to another within the atmosphere. Knowledge about the waves can help clarify our understanding of the ultraviolet-to-thermal energy conversion and the workings of the upper atmosphere in general.

The structure of upper atmospheric gravity waves is made visible by the wavelike noctilucent clouds present primarily in summer in the mesosphere above latitudes north of 50 degrees. WAMDII's greatest challenge is to detect these wave structures and characterize their sizes and orientations. The instrument's imaging ability may allow it to make the first definitive and direct measurements of such phenomena.

Noctilucent clouds, which form five times higher than any other cloud, are illumined by the sun when it is over the horizon and are thus only visible in the dark after sunset.

Photo courtesy of O. van Dongen, Saskatoon, Saskatchewan, Canada

ORIGINAL PAGE
COLOR PHOTOGRAPH

IV. Orbit Operations

WAMDII is tentatively planned as a four-day mission. Approximately 50 hours of observations will be made during this time. In order to transmit to Earth the vast amounts of data collected, WAMDII can operate only when the Shuttle is in the range of one of NASA's Tracking and Data Relay Satellites (see Section X — Data Flow). The instrument's field-widened imaging capacity allows it to acquire more upper atmospheric temperature and wind-speed data than any previous instrument. A wind-speed image (from which temperature data is also derived) can be taken roughly every 15 to 30 seconds. Each image consists of 9,000 measurements. Over 50 hours, WAMDII's imaging capacity will produce thousands of images. A minimum of three images is needed to make one temperature and wind-speed reading from each emission range observed.

In order to create a comprehensive picture of upper atmospheric weather dynamics, WAMDII must be able to measure both day and nighttime airglow emissions. During the day, the sun illuminates the Earth and this very bright light is reflected off the clouds and into space. This light is perhaps a million times brighter than the light of the airglow emissions WAMDII will observe to derive upper atmospheric wind-speed and temperature measurements. Airglow measurements, however, can still be made during the day due to WAMDII's long baffle system (shown in Cutaway Illustration of WAMDII in on page 13) which excludes the sunlight reflected from Earth.
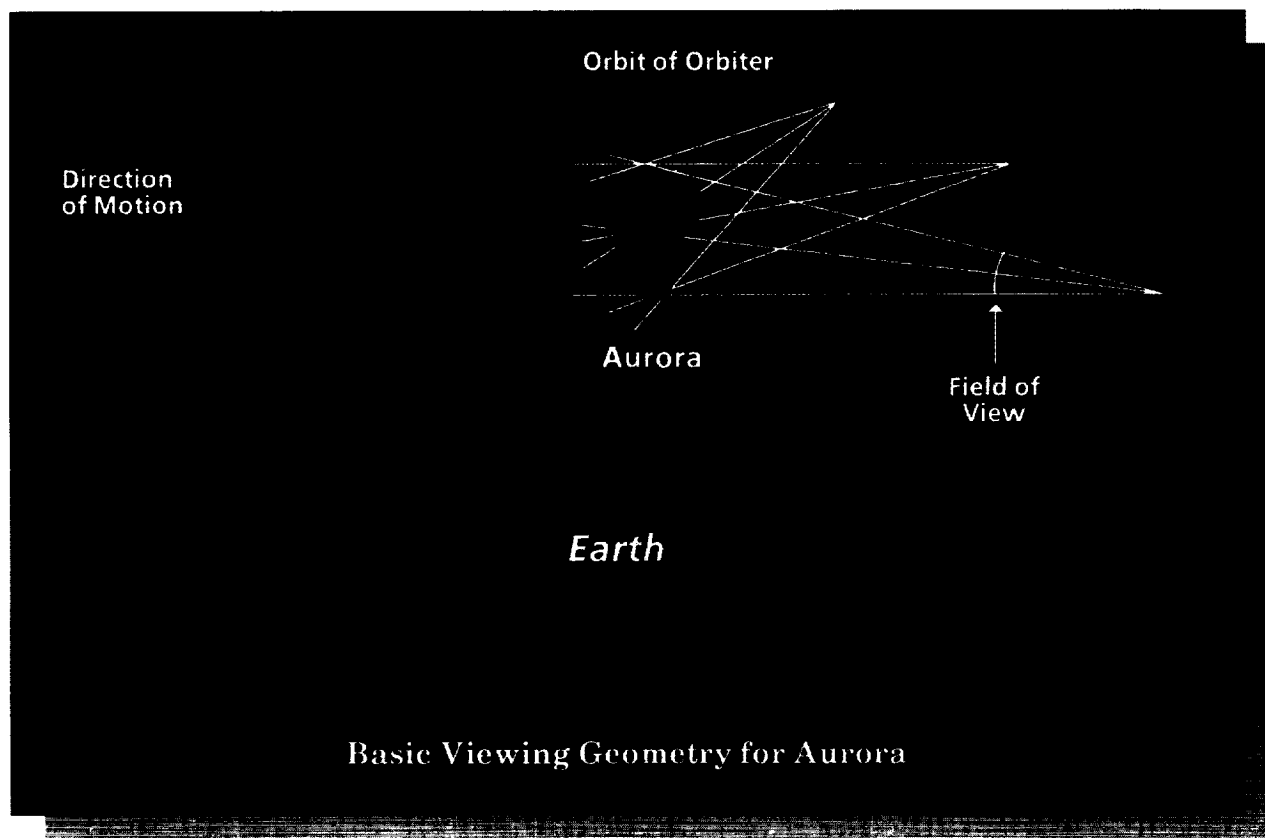

Basic Viewing Geometry for Airglow
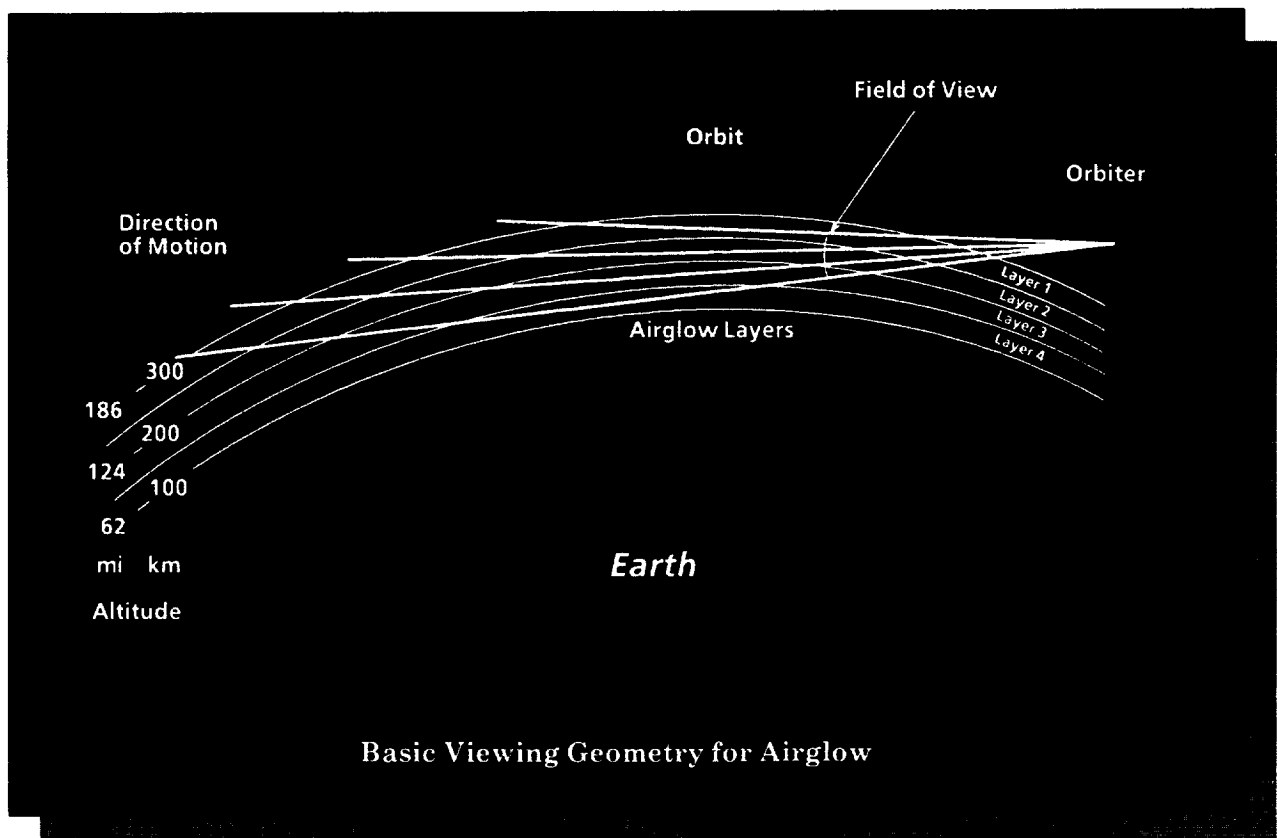
The altitude of the orbiter during the mission will be slightly above the uppermost airglow layers to be observed. WAMDII's strategy is to look down at the airglow layers at an angle just below a horizontal inclination, as shown in the "Basic Viewing Geometry for Airglow" illustration, rather than vertically downward. In this way, wind-speed and temperature profiles are derived as a function of altitude.

One advantage of this method is that it allows more of the emitting atoms in the airglow to be seen; thus, the intensity of the viewed light will be greater than if the emissions were viewed vertically. Since light from the airglow is weak, this is a tremendous advantage. Furthermore, horizontal viewing avoids any varying of the amounts of light reflected from the sun, moon, or airglow itself off of underlying clouds.
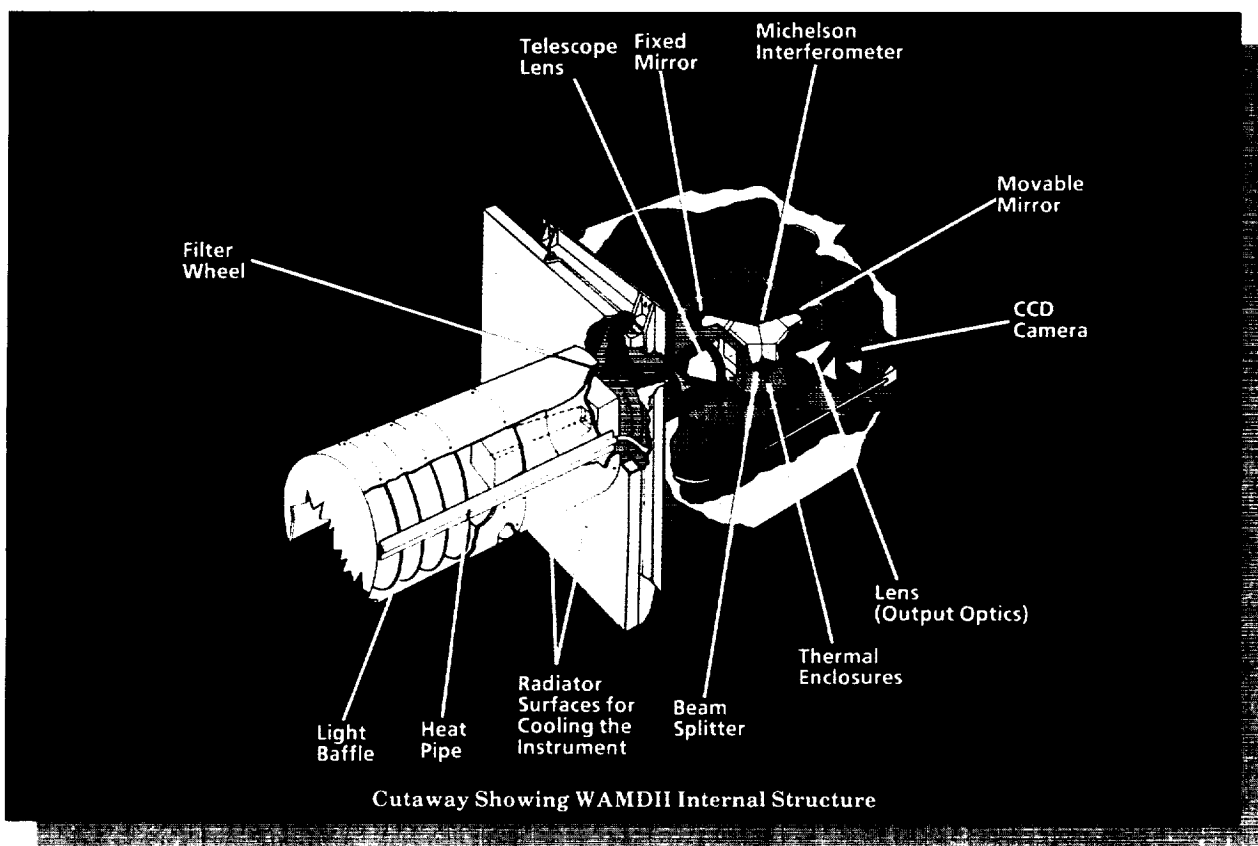
The "Basic Viewing Geometry for Airglow" illustration shows that only layer 1 is intersected by the topmost portion of the instrument's line of sight. Thus, WAMDII will obtain a correct wind-speed and temperature reading for this altitude covering the range between approximately 160 and 190 miles above the Earth (250 and 300 km). The next view down, however, intersects both layers 1

and 2, so the winds and temperatures for these two layers are mixed together. Layer 1 is viewed twice; since it is already known what the wind and temperature are in this layer, these amounts can be subtracted from the observations of the layers 1 and 2. This way the wind speed and temperature are determined for layer 2 only. Using a computer, this process, known as "onion peeling," can be continued downward to the lowest layer, shown here at approximately 60 to 90 miles (100 to 150 km) above the Earth. The general name for the process of unscrambling or separating out the different pieces of data is "inversion." The computer inverts the scrambled data to recover the true distributions of wind and temperature in the atmosphere as a function of altitude.

This technique works well for airglow, which exists in relatively uniform layers around the Earth. But for the aurora, which is a structure present only at certain times in certain regions, the technique is not useful. If the views from different directions, as shown in the "Basic Viewing Geometry for Aurora" illustration, can be combined, however, the position of the auroral light can be located horizontally as well as vertically. This process is known as "two-dimensional inversion."

Basic Viewing Geometry for Aurora

V. How WAMDII Works

Telescope Lens · Fixed Mirror · Michelson Interferometer · Movable Mirror · CCD Camera · Filter Wheel · Lens (Output Optics) · Thermal Enclosures · Radiator Surfaces for Cooling the Instrument · Beam Splitter · Light Baffle · Heat Pipe

Cutaway Showing WAMDII Internal Structure

Basically, WAMDII is a camera. Instead of taking pictures with film, it makes electronic images of airglow emissions in the upper atmosphere. From these images, measurements of wind speed and temperature are derived.

• How WAMDII Measures Wind Speed

To make wind-speed measurements, WAMDII uses the airglow as a tracer to measure the bulk movement of the air. The Doppler effect phenomenon is the key to understanding how wind-speed measurements are made by observing airglow emissions. This effect is illustrated in how the wavelength of light from a moving source changes by an amount proportional to the velocity of the source. In the context of WAMDII, the source is the airglow emissions; the emissions are moving and the shift in wavelength indicates at what speed.

The term Doppler shift, refers to the motion of sound as well as light waves. A familiar example is noted in how the pitch of a train whistle drops off as the train passes by. When a train moves toward a passenger waiting on the platform, for instance, the sound waves it has emitted farther back are closer to the more recently emitted waves than they would normally be; the waves become compressed. This compression causes them to reach the listener

at a high frequency. As the train moves away, the waves are stretched and reach the listener at a lower frequency. If the pitch of the train whistle is known, the train's speed can be determined by measuring how the sound wave frequency has shifted. These same stretching and compression shifts occur when airglow emissions are moved by the wind. Scientists already know the light frequency of airglow emissions. If the wavelength shift of the airglow can be measured, wind velocity can then be calculated by an equation.

In the case of WAMDII, which will be mounted on the Shuttle, care must be taken to correct for the motion of the spacecraft which, by moving towards or away from the source being measured, produces a Doppler shift of its own. This must be subtracted from wind-speed measurements.

Different airglow layers appear at different altitudes, each layer having a predominance of emissions at certain wavelengths. In order to measure Doppler shift, WAMDII needs to work with a pure frequency. This means that it can observe only one emission line, hence one altitude range, at a time. A filter wheel is used to select the proper frequency for the airglow emission chosen for observation at any given time. Different filters are used to observe different emissions.

The filter is changed according to a timeline, a set of commands stored in the instrument's computer memory which control all the necessary functions. Commands sent from Earth designate which filter to use to view a certain emission, along with the exposure time and other information. When the instrument has carried out these commands, additional commands to last for several orbits are sent and completed.

Before light enters the interferometer itself, it passes through a baffle (to block unwanted sunlight reflected from the Earth and its atmosphere) and a telescope. The telescope determines WAMDII's field of view, the area in the sky to be viewed in each image. The telescope also focuses the airglow emission to produce a well-defined beam which then passes through the interferometer. This

eliminates light that might be scattered by glass edges and mountings on the outside of the instrument. Since airglow emissions are faint, getting as much light as possible is a challenge. The telescope also helps the interferometer realize its maximum light-gathering capacity.

To obtain wind-speed measurements from airglow emissions, WAMDII creates an interference pattern of the light being measured. This pattern, or interferogram, is a visual representation of the wavelength of a light beam. It is made by splitting the beam of light that enters the instrument into two paths of different lengths and then recombining the light again into a single beam. This recombination of beams or interference is extremely sensitive to wavelength shifts. This concept serves as the basis of the WAMDII instrument.

How Light Is Split in the Michelson Interferometer
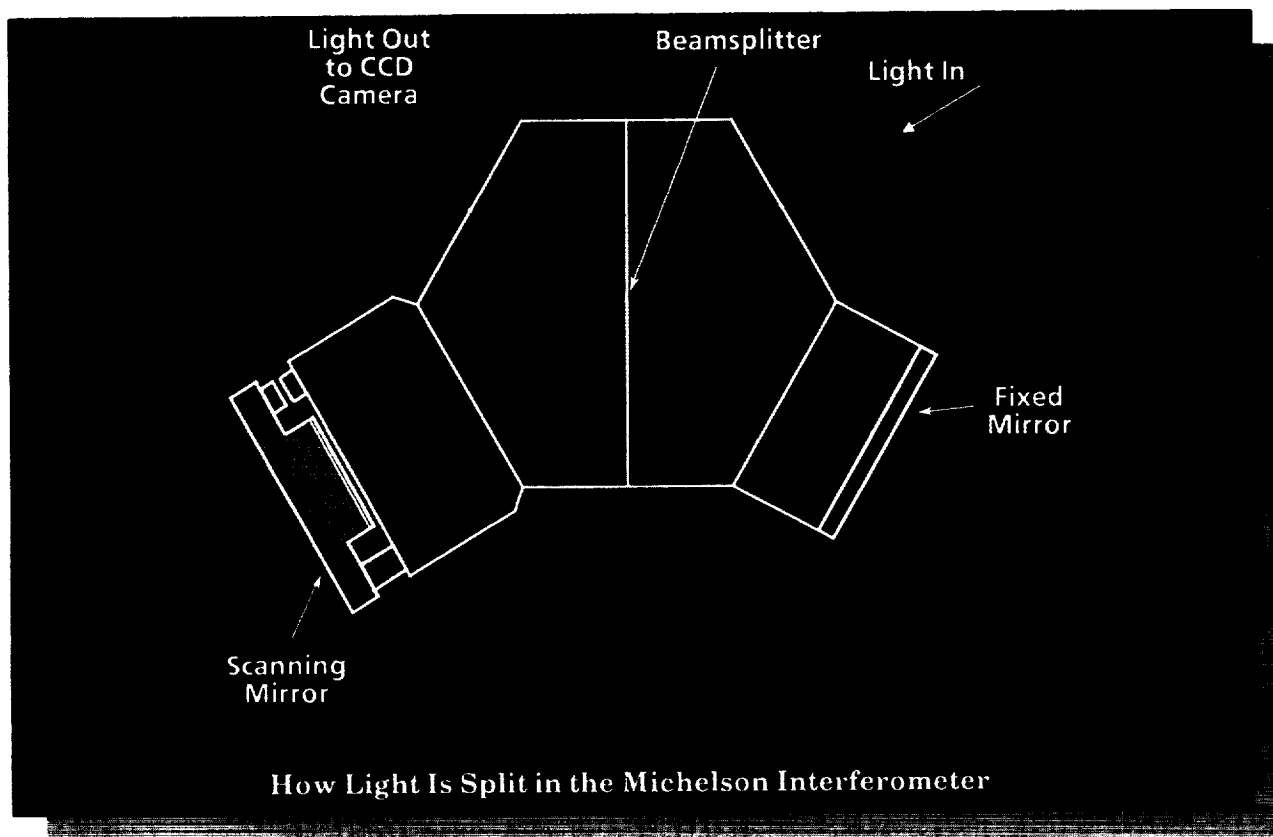
A light beam entering the interferometer from the telescope, first contacts a beamsplitter. The beamsplitter is a partially reflective mirror which allows half of the light that strikes it to pass directly through, while the other half is reflected at an angle. Thus, a single emission beam is split into two beams of equal intensity. The beams travel different paths to two different mirrors, one moveable and one stationary. After reflecting off the mirrors, they recombine at the same beamsplitter and are imaged by a lens onto a Charge Coupled Device (CCD) camera.

The CCD camera contains a grid of 80,000 pixels, small elements that together make up an image similar to that on a television screen. As light from airglow emissions exits the interferometer, it is focused onto the CCD camera, leaving an electrical charge stored on each pixel it contacts. The amount of charge depends on the light intensity at that pixel. This creates an image of the interferogram on the CCD pad, the bright and dark bands of which are called fringes. It is by examining the position and contrast of these fringes that wind-speed measurements are derived.

The distance one of the two split beams must travel is varied by shifting the moveable mirror in small steps. Four different images are taken of each measured emission with the mirror in a different position for each image. Moving the mirror by steps modulates the intensity of the light beams to create an interferogram for each pixel. When the two beams created by this split recombine, they will either interfere with each other (cancel out each other) and thus produce a dark fringe, or reinforce each other and create a bright one. The Doppler effect produces small shifts in this pattern. "Shift," as used here, refers to a change from a level of zero movement. By comparing this change to images created in a laboratory of emissions which are not moving, the difference is noted and a velocity measurement is made.


Light and dark fringes visible on an interferogram.
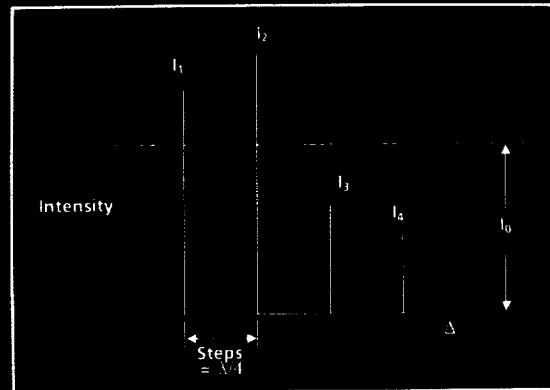
Graph Showing Intensities of the Four CCD Images

The results of the four measurements of the interference pattern correspond to the intensities I_1, I_2, I_3, and I_4, shown in this model of the CCD chip grids. The I_1 image shows a circle of moderately bright intensity. Intensity increases at I_2. I_3 is a bit darker and I_4 is very dark.
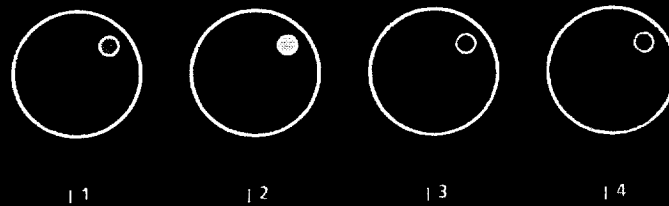
Four CCD Images With a Phase Shift Between Each Image

The different intensities for this pixel can then be represented graphically.

When the intensities obtained from the four images are assigned numerical values, they can be put into an equation which allows the phase shift and hence the wind velocity to be calculated.

WAMDII is the first field-widened imaging interferometer for Doppler measurements to be flown in space. The field-widening feature allows more data to be obtained from the imaged interferograms. Most of the useful data from an interferogram is found in the central portion of the fringe image. Field widening means that WAMDII expands the area of this useful portion of the

interferogram by a factor of 1,000, as shown in the photo below comparing conventional versus field-widened Michelson fringes. With the conventional Michelson, the central fringe is such a tiny spot that only a single-point measurement can be made. To create an image this way would require focusing the instrument on each point in space and making a measurement at each point; this would take a very long time. WAMDII measures all 80,000 of its image points simultaneously, acquiring vast amounts of data in a short time. Because all these data refer to a single Space Shuttle location, they are easier to interpret.

The full field of view covered by an image is approximately 10 degrees square. In this 10° square area all 80,000 image points are recorded.

Although the procedure for producing an image seems complex, an interference pattern must be made in order to make wind-speed and temperature measurements from airglow emissions. If light from airglow and auroral emissions were simply imaged without passing through the Michelson interferometer to create an interferogram, an image like that from a conventional camera would be made. Bright and dark regions would be apparent, but none of the fringes necessary for deriving temperature and wind data would be.
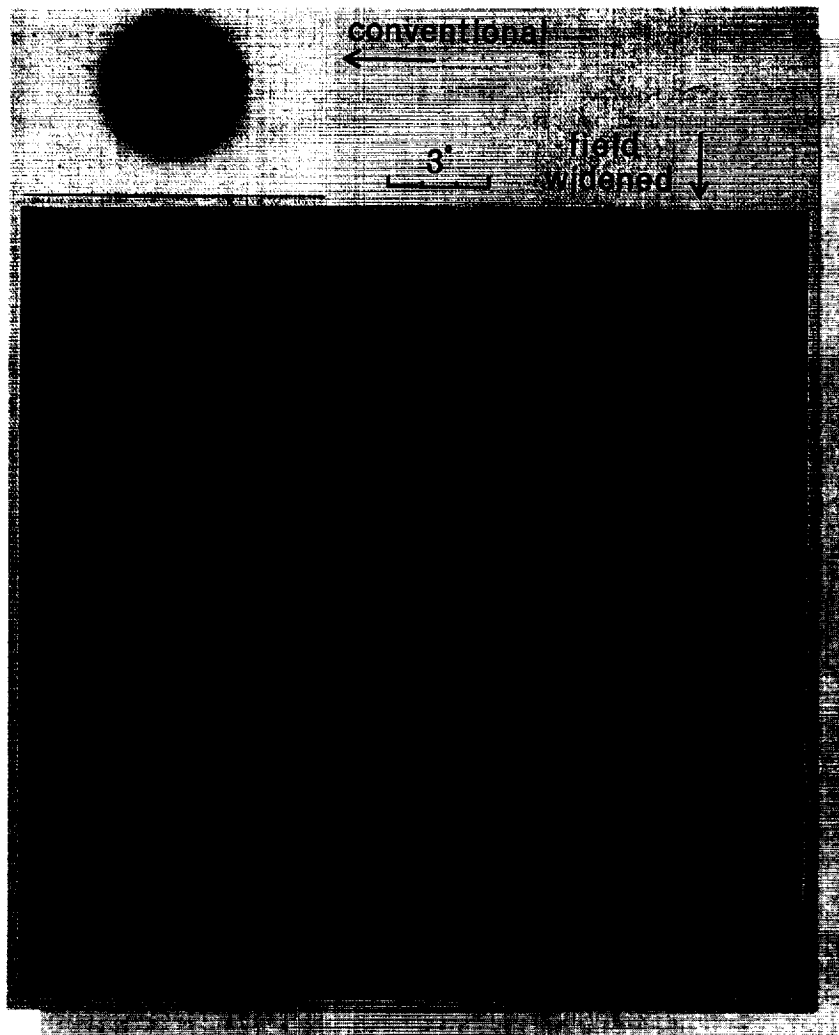
Fringe images taken by two interferometers otherwise identical except for their capacities to take conventional vs. field-widened images.

• How WAMDII Measures Temperature

Airglow emissions also provide the basis for WAMDII's upper atmospheric temperature readings. The higher the temperature of an airglow emission, the faster the atoms within it are moving randomly. The faster the atoms are moving, the wider the spectral lines they emit. As the emission lines become broader, the contrast or visibility of the interferogram fringes decreases. By using the peak to valley height (visibility) of the interferogram fringes as a gauge, temperature measurements are derived. Numerical representations of fringe visibility are converted to temperature readings by an equation. The visibility image is the key to temperature measurements and the phase image serves as the key to velocity measurements.

In addition to wind speed and temperature, the intensity of the airglow can also be determined from the intensities of the four different images appearing on the CCD grids. Intensity is also a useful research parameter serving as an indicator of the photochemical processes taking place at this altitude. These processes affect how energy is transferred from one place to another in the upper atmosphere as well as how it is transformed from a state of ultraviolet energy into the heating state of thermal energy.

Once the visibility and phase images are determined, they are color-coded by computer to produce false color images of the wind speed and temperature. This is a simple way of giving scientists a general idea of what can be looked for in interpreting the vast amount of data collected. Color differences along a vertical column indicate a temperature gradient in the atmosphere. A patchy appearance on a phase image would demonstrate the existence of high localized winds.
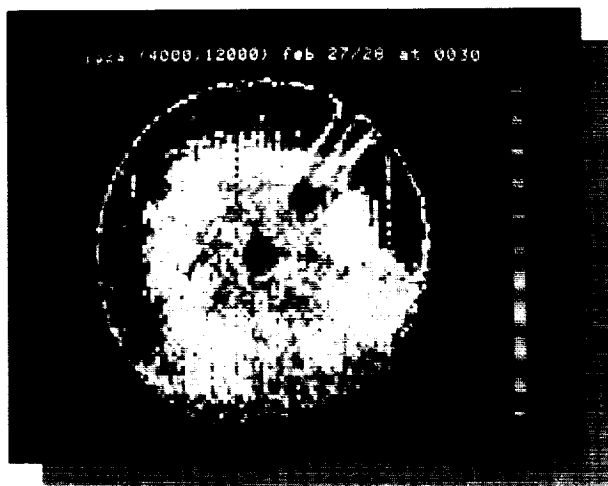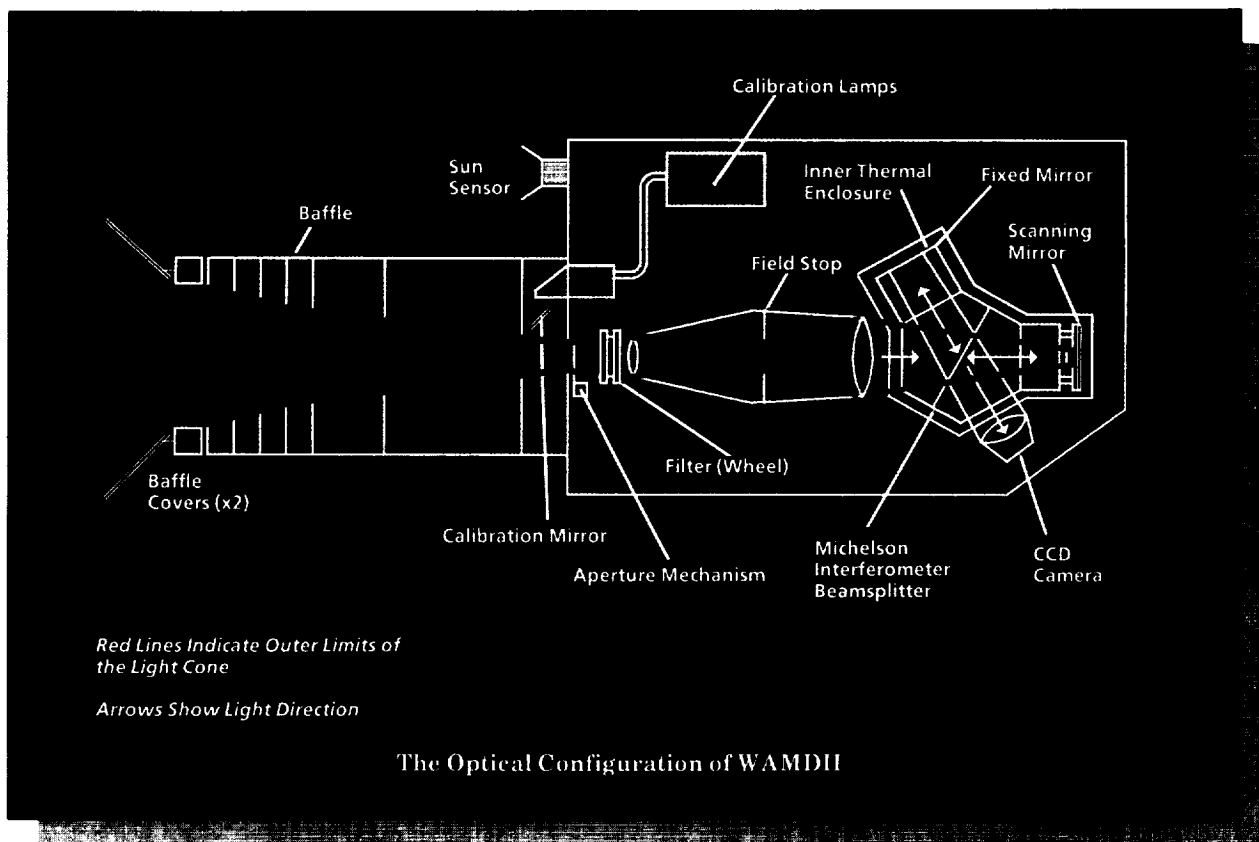

Figure a.
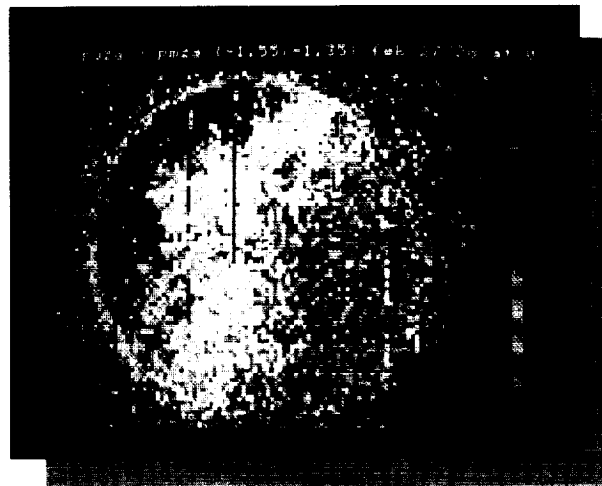
Figure b.

A false color view of an aurora-filled sky as seen from Saskatoon, Saskatchewan by WAMDII through an all-sky lens. North is at the top. Note that most of the intensity (figure a) covers the northern sky from the East horizon to the West horizon. The corresponding wind (b) is shown by the change of color or phase across the zenith (center of the disk).

WAMDII Construction

"The Optical Configuration of WAMDII" shows several subsystems that are required to produce reliable data. Calibration lamps give images which provide a reference for measurements of phase, visibility, and intensity images of the atmosphere. An aperture control mechanism reduces the light intake during the day, and the baffle doors protect the instrument when not in use.
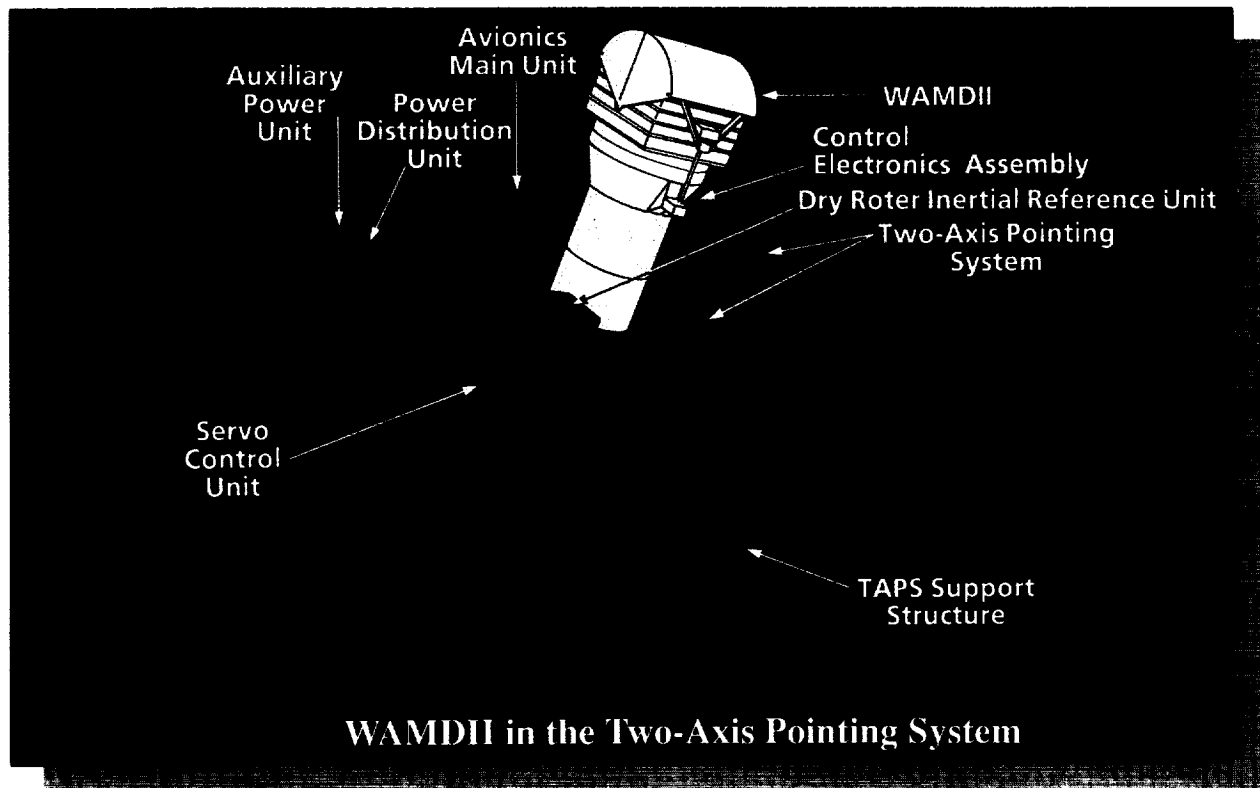

The Optical Configuration of WAMDII

The interferometer is shown as the hexagonal unit in the right of the figure. It is made of several large blocks of blemish-free glass ground and polished at the working surface to a flatness of a tenth of a wavelength of light. The stationary mirror is coated directly onto one such surface. The moveable mirror is held to the interferometer arm by quartz pillars which are expanded and contracted by varying the voltage across them; this is called the piezoelectric effect. To maintain the strict orientation of this mirror, capacitive sensors measure the mirror distance at several points in a bridge circuit that controls the piezoelectric voltages. The steps the mirror makes are governed by the Instrument Control and Data Handling (ICDH) computer, as are: the position of the filter wheel; the states of the calibration mirrors and lamps; the baffle covers and the aperture stop; and the operation of the CCD camera. The ICDH computer will receive commands from the Payload Operations Control Center (POCC). (See Mis-

sion Operations Responsibilities — Section VIII.) It implements the command as scheduled and returns the data via the Shuttle Payload of Opportunity Carrier (SPOC) avionics system (see Payload Development — Section VII) to the WAMDII ground support computer which monitors and stores the data.

In order for WAMDII to operate effectively, the instrument's temperature, and that of the interferometer in particular, must be regulated. The thermal control system makes this possible. The heat pipes transfer heat to the baffle which then radiates the heat out to space. Electrical resistors are used when heat must be added to the system to maintain constant temperature. The set of thermal enclosures around the Michelson interferometer assures that this part of the instrument will remain stable at room temperature, the temperature at which it was designed to operate.

VI. TAPS — NASA's Two-Axis Pointing System

Auxiliary Power Unit · Avionics Main Unit · Power Distribution Unit · WAMDII · Control Electronics Assembly · Dry Roter Inertial Reference Unit · Two-Axis Pointing System · Servo Control Unit · TAPS Support Structure

WAMDII in the Two-Axis Pointing System

NASA's Two Axis Pointing System (TAPS) facilitates the selection and tracking of the emission sources WAMDII will be observing. WAMDII will be used to set the TAPS' frame of reference by locating the position of certain bright stars. Once the reference is fixed, the gyros attached to WAMDII will help keep TAPS positioned for observation of the selected target. But because the gyros, by nature, will begin drifting, the reference must be periodically checked and reset by using WAMDII as a star tracker.

The TAPS will remain secured by a Support Structure in the orbiter payload bay throughout the mission. Receiving near-real-time commands from the Payload Operations Control Center during the mission, TAPS will allow pitch, roll, or a combination thereof to point WAMDII at given observational targets.

TAPS has been developed by Goddard Space Flight Center for multiple-mission use. Its outer frame, connected to the TAPS Support Structure, is stationary. Mounted on top of the outer frame are three electronic boxes: a servo control unit, a power distribution unit, and a control electronics assembly.

A pitch drive brake assembly and a pitch idler assembly will allow an inner gimbal frame to move WAMDII upon remote command in a forward/aft direction (pitch) relative to the orbiter payload bay. Since the Shuttle will always fly with its nose vertically upward, the pitch motion is up and down.

A roll drive brake module and a roll idler module, which connect WAMDII to the inner gimbal frame, will allow WAMDII to move from side to side (roll) relative to the payload bay.

A TAPS sensor, a three-axis gyro system called the Dry Rotor Inertial Reference Unit (DRIRU), will be mounted on WAMDII to provide a precise inertial reference for WAMDII positioning information.

ORIGINAL PAGE
COLOR PHOTOGRAPH

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VII. Payload Development

• Development of Individual Components

NASA's GSFC has responsibility for developing the TAPS and the TAPS Support Structure. The WAMDII Science Team is responsible for scientific aspects of WAMDII, while the National Research Council of Canada funds the development and fabrication of the instrument. SED Systems in Saskatoon, Saskatchewan, is the prime contractor responsible for building the instrument.

*NASA and Canadian WAMDII Personnel examine components.**
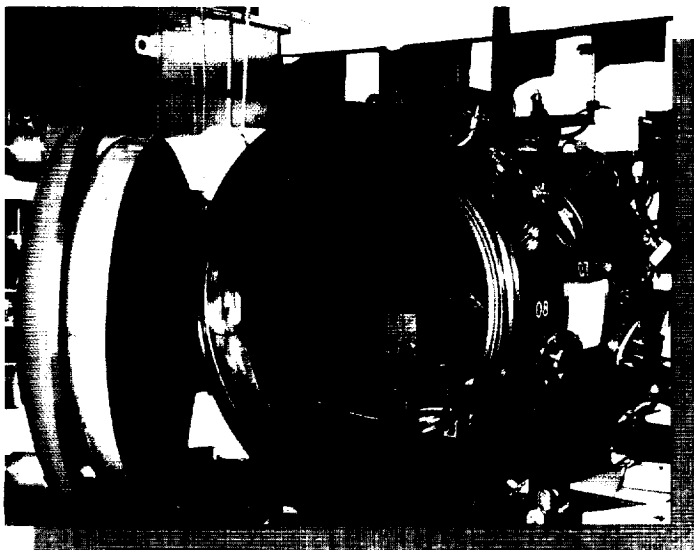
*WAMDII components are ready for testing in a 1 meter x 1 meter thermal vacuum chamber at David Florida Laboratory in Ottawa, Ontario.**

*Photo courtesy of the David Florida Laboratory,
 Department of Communications, Government of Canada.*

GSFC is providing a standard SPOC avionics system (mounted on the TAPS Support Structure). The avionics will allow communication during the mission between WAMDII and the WAMDII Payload Operations Control Center at GSFC.
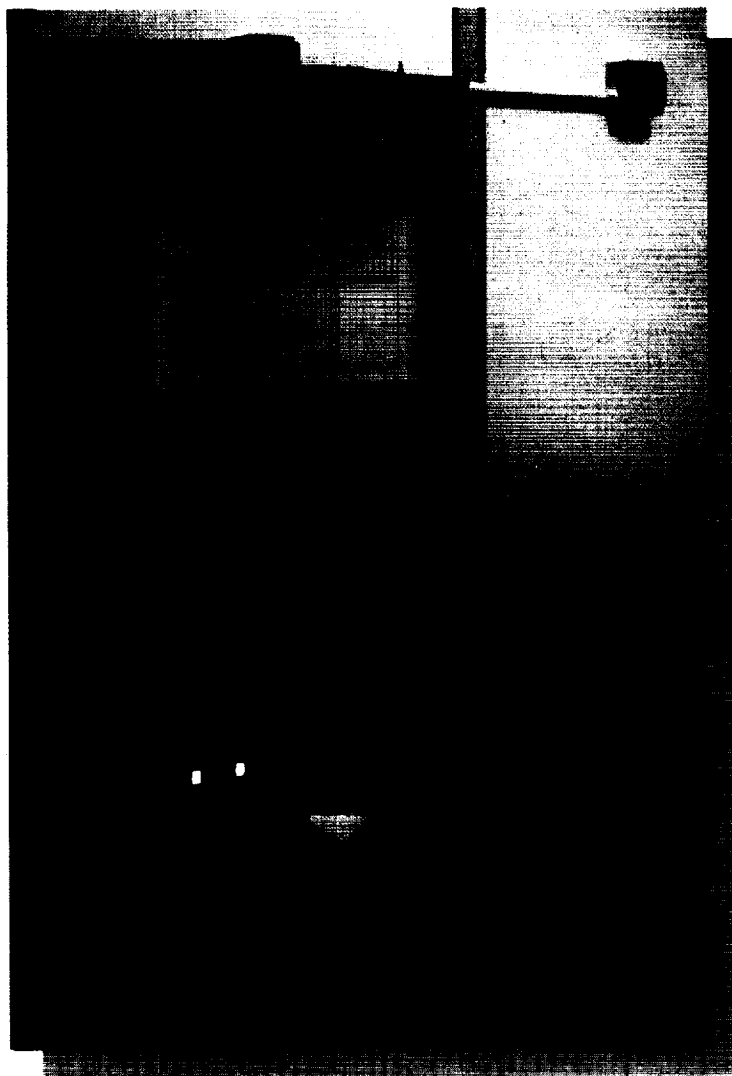
• *Integration and Test*

After fabrication, but before WAMDII is delivered to GSFC, the instrument will undergo thermal vacuum, vibration, and Electromagnetic Interference (EMI) testing at the David Florida Laboratory in Ottawa, Canada.

First, the instrument's weight and center of gravity are determined. Then the instrument and associated ground support equipment will be sent to GSFC for mechanical and electrical integration with the Two-Axis Pointing System and the TAPS Support Structure. The entire payload will then be subjected to acoustic, EMI and Electromagnetic Compatibility (EMC) testing in various GSFC facilities. The EMI test assures that a payload's level of electromagnetic activity, both radiated and conducted, will not affect other payloads on the orbiter or the orbiter itself. The EMC test checks to determine if a payload will be susceptible to the electromagnetic levels of other payloads on the orbiter.

After payload testing at GSFC is successfully concluded, the WAMDII payload will be transported by truck from GSFC to Kennedy Space Center (KSC) in Florida for integration with the orbiter. First, GSFC and SED Systems personnel at KSC will run a post-shipment functional test followed by a data flow test between the WAMDII payload at KSC and the WAMDII Payload Operations Control Center (POCC) at GSFC. Then orbiter integration will begin.


GSFC is responsible for conducting Electromagnetic Interference and Electromagnetic Compatibility tests for the WAMDII payload after integration is complete.

VIII-1 Launch and Landing

In addition to WAMDII payload integration into and removal from the orbiter at Cape Canaveral, Kennedy Space Center personnel are responsible for Shuttle launch and landing procedures and operations.
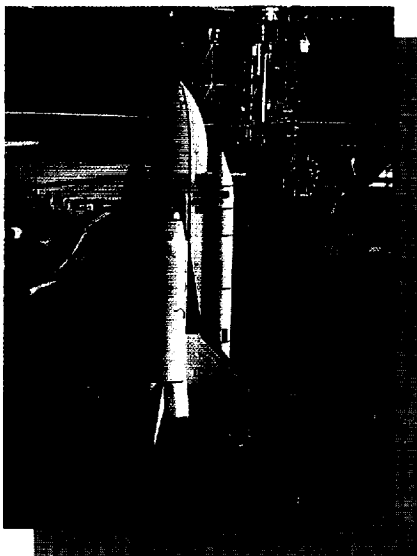

Shuttle being taken to the launch pad at KSC.

VIII-2 Mission Operations Responsibilities

Responsibility for the WAMDII Mission Operations rests with Goddard Space Flight Center's WAMDII Payload Operations Control Center (POCC) in Greenbelt, Maryland. This POCC will be managed by a GSFC Mission Operations Manager who is responsible for WAMDII flight operations planning and execution.

As with all attached Shuttle payload missions, Johnson Space Center (JSC) in Houston, Texas, is responsible for all Shuttle crew procedures and operations, including mission control in the Shuttle Mission Control Center at JSC during flight. The primary JSC/GSFC interface for the WAMDII mission is the JSC Payload Officer who serves as JSC's point-of-contact with the GSFC POCC during WAMDII operations.
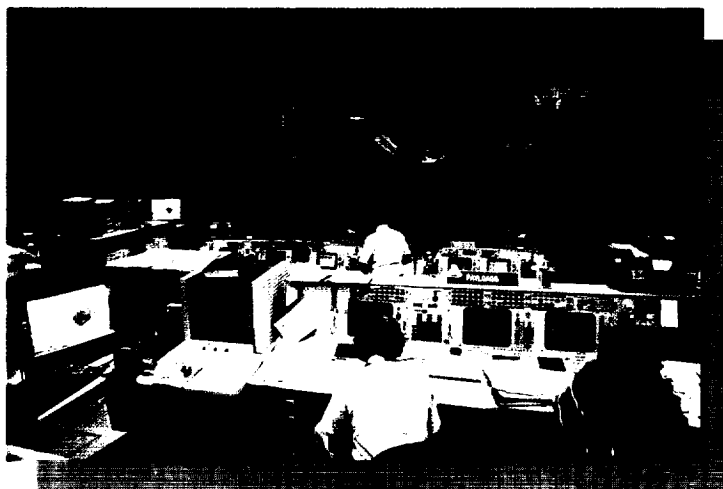
A Payload Officer at Johnson Space Center's Mission Control Center serves as the point-of-contact between Mission Control and the GSFC Payload Operations Control Center during WAMDII operations.

In addition to NASA's Payload Operations Control Center personnel, the POCC will be manned by Goddard Space Flight Center's TAPS representatives and Canadian mission team representatives during the WAMDII mission. POCC personnel will interface between the experimenters and JSC's Mission Control Center. WAMDII personnel (SED Systems and the Science Team) will command WAMDII activities (including recommending TAPS posi-

tioning), calibrate WAMDII, and monitor scientific data which the instrument gathers. Early in the mission, TAPS personnel will check out TAPS from the POCC; they will then implement the TAPS position commands and serve in a monitoring capacity. WAMDII personnel will conduct WAMDII flight operations, calibration, and monitoring of scientific data, as well as make initial interpretations of the scientific data.

Payload Operations Control Center (POCC) personnel at GSFC send commands to the WAMDII payload during the mission.

IX. Mission Operations

Once the Shuttle is in orbit, an astronaut inside the Aft Flight Deck will activate WAMDII by turning on the avionics via the Aft Flight Deck Standard Switch Panel. Next, POCC personnel at GSFC will turn on the avionics subsystems and WAMDII. Actual scientific observations will not begin until after deployment of any "free-flying" satellites which might be manifested on the flight.

Initial POCC commands will put WAMDII in a "stand-by" mode with both power and heaters on. A system check and WAMDII/TAPS alignment calibration will follow. Before scientific operations begin, WAMDII Science Team personnel will have created a set of commands for data-taking operations which will be transmitted to the instrument for execution. The astronauts will orient the Shuttle in the required direction. This attitude will be determined pre-launch by the investigators and GSFC Flight Dynamics personnel with approval by Johnson Space Center. To assist POCC operations, GSFC Flight Dynamics Facility personnel will generate a detailed timeline mission profile for proper instrument operating constraints. They will also monitor the orbiter attitude at all times during the flight.


GSFC Flight Dynamics Facility personnel will generate a detailed mission timeline and monitor orbiter attitude during the WAMDII mission.

Once instrument observations begin, POCC personnel will monitor telemetry from the SPOC avionics, while SED Systems personnel monitor WAMDII operations. The WAMDII Science Team members will monitor and interpret the scientific data from the displayed images.

As the end of the mission is reached, POCC personnel will turn off the WAMDII and TAPS heaters and power, and prepare the avionics for remote "turn off" by an astronaut in the Aft Flight Deck. Once the avionics is turned off, POCC responsibilities will come to an end.

X. Data Flow
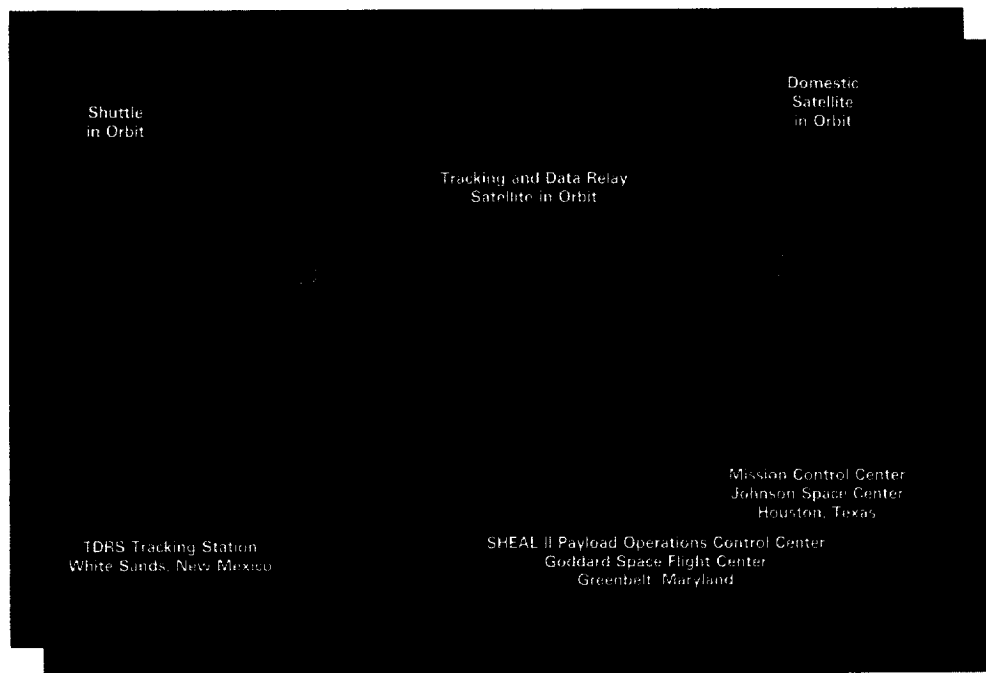
Data Flow Sequence

Data from the orbiter will be transmitted: 1) to a NASA Tracking and Data Relay Satellite (TDRS); 2) to a Tracking Station in White Sands, New Mexico; 3) to the NASA Domestic Satellite (DOMSAT), and 4) to Goddard Space Flight Center and Johnson Space Center. The SPOC avionics system generates two types of data, low-rate and medium-rate. Low-rate or "housekeeping" data is generally engineering data that reports on the status of the instrument; it includes voltage and current readings, relay statuses, and temperature measurements both inside the instrument and at various points throughout the payload. Some science data also may be included with these transmissions. Low-rate data is transmitted at 8 kilobits per second. Medium-rate data, on the other hand, generated at 2 megabits per second, is science data from which WAMDII images are derived. These images will be translated into wind-speed and temperature measurements. Medium-rate scientific data will be transmitted directly to the POCC at GSFC. Low-rate scientific and housekeeping data will be transmitted through JSC's Mission Control Center to the POCC. The GSFC Shuttle/POCC Interface Facility will supplement the operations interface between the GSFC POCC and the JSC Mission Control Center.

GSFC's Spacelab Data Processing Facility (SLDPF) will process and sort all medium-rate data. This facility will be responsible for supplying medium-rate data tapes to the experimenters one month after the WAMDII Mission. The SLDPF also supplies low-rate scientific and housekeeping data tapes, while the Sensor Data Processing Facility at GSFC will supply Shuttle ancillary data tapes (orbiter-related information) to the experimenters one month after the mission.

After the mission is concluded, all analysis of data obtained by WAMDII will be the responsibility of the WAMDII Science Team. The data will be made available within a year to the general science community.

*Spacelab Data Processing Facility personnel at GSFC are responsible
for processing and de-multiplexing all medium-rate WAMDII data.*

XI. Canadian WAMDII Key Personnel

Principal Investigator (PI)

Dr. Gordon G. Shepherd
York University
Toronto, Ontario, Canada
(416) 736-2100 ext. 3221

The WAMDII Principal Investigator (PI) heads the WAMDII Science Team. The team develops all of WAMDII's science requirements and creates an observational program which specifies scientific targets, duration, and mode of WAMDII operation. The team also monitors the development of the instrument to ensure it can meet all scientific objectives. During the WAMDII mission, the PI will head the WAMDII team which is coordinating observations remotely from the POCC at GSFC. After the mission, he is responsible for overseeing the reduction and analysis of data obtained by WAMDII.

Deputy Principal Investigator

Dr. Rudy H. Wiens
York University
Toronto, Ontario, Canada
(416) 736-2100 ext. 7719

The Deputy Principal Investigator serves as liaison between the Science Team and the National Research Council of Canada on an ongoing basis. He is also responsible for the detailed operational plans and data analysis software.

York University's WAMDII Deputy Principal Investigator Rudy Weins (seated), Dr. William Gault, co-developer of the WAMDII concept (center,) and Dr. Gordon Shepherd, WAMDII Principal Investigator and concept co-developer.

Co-Investigators/Science Team:

— University of Calgary: Dr. L. L. Cogger
Dr. C. D. Anger
Dr. J. W. Haslett

— University of Saskatchewan:
Dr. E. J. Llewellyn
Dr. K. V. Paulson

— Herzberg Institute of Astrophysics,
National Research Council Canada:
Dr. R. L. Gattinger

— York University:
Dr. J. C. McConnell
Professor R. A. Koehler

— University of Western Ontario:
Dr. D. R. Moorcroft

Canadian/WAMDII key personnel: (l to r) Terry McCawley,
Romeo Wlochowicz, Patricia Mortimer, and Doug Miller

WAMDII Project Manager

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Science Procurement Officer

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Project Manager

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SED Systems, Inc.
Saskatoon, Saskatchewan, Canada
(306) 933-1419

Deputy Project Manager

Terry McCawley
SED Systems, Inc.
Saskatoon, Saskatchewan, Canada
(306) 933-1424

The Canadian WAMDII Project Manager is the Federal Government (National Research Council of Canada) employee who, on one hand, is accountable for the money spent on the project and, on the other hand, works closely with the Principal Investigator to ensure that the scientific instrument meets the specifications of the Science Team. The arrangement provides a service to the scientific community by removing from them the burden of issuing and monitoring contracts.

The Science Procurement Officer of the Canadian federal Department of Supply and Services is responsible for the negotiation, award, and management of contracts for the design and fabrication of the WAMDII instrument. Contractor performance on various contracts is monitored by this official, who also acts as a liaison between NRCC and the contractors.

The SED Systems WAMDII Project Manager is responsible for the development of the entire WAMDII System including management, design, fabrication, testing, verification and provision of preflight support services. He is also the engineer responsible for all matters pertaining to the optical design.

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XII. NASA WAMDII Key Personnel

WAMDII Program Manager

Earl Montoya
NASA Headquarters
Washington, D.C.
(202) 453-1689

WAMDII Program Scientist (Acting)

Owen Storey
NASA Headquarters
Washington, D.C.
(202) 453-1522

WAMDII Mission Manager

Frank Volpe
Goddard Space Flight Center
Greenbelt, Maryland
(301) 286-7791

WAMDII Instrument Manager

John Laudadio
Goddard Space Flight Center
Greenbelt, Maryland
(301) 286-7800

WAMDII Mission Scientist

Sushil Chandra
Goddard Space Flight Center
Greenbelt, Maryland
(301) 286-8743

WAMDII Mission Operations Manager

Bruce Thoman
Goddard Space Flight Center
Greenbelt, Maryland
(301) 286-7494

The WAMDII Program Manager is part of the Flight Systems Division of the Office of Space Science and Applications (OSSA) at NASA Headquarters. As the top-level manager of the mission, he is responsible for allocating funds and overall program management.

The WAMDII Program Scientist comes from the Space Physics Division of OSSA at NASA Headquarters. His role is to provide science support and direction for the mission.

The WAMDII Mission Manager is part of the Explorer and Attached Payloads Project at Goddard Space Flight Center. As Mission Manager, he has the prime responsibility for the mission including cost, schedule, and performance. He directs and reviews all mission phases to facilitate the planning and execution of the mission and is the primary interface with other NASA facilities on matters relating to the mission. He is also responsible for interface validation and safety compliance related to payload performance.

The WAMDII Instrument Manager is also part of GSFC's Explorer and Attached Payloads Project. He serves as technical manager and coordinator for payload development, including instrument interface with the TAPS and TSS, SPOC avionics, the orbiter, ground systems, flight planning and mission operations, and instrument integration.

The WAMDII Mission Scientist, who is part of GSFC's Laboratory for Atmospheres, is responsible for coordinating the overall payload scientific system, the scientific aspects of mission operations, and data reduction requirements. He serves as the primary point-of-contact on scientific matters between NASA and WAMDII's Principal Investigator.

The WAMDII Mission Operations Manager (MOM) is assigned by the GSFC Mission Operations and Data System Directorate to the GSFC Explorer and Attached Payloads Project. The MOM is responsible for managing flight operations planning and execution, as well as delivering science data tapes to the experimenters after the mission.

*NASA/GSFC key personnel for the WAMDII mission: (l to r) Frank Volpe, Mission Manager;
John Laudadio, Instrument Manager; Sushil Chandra, Mission Scientist;
and Bruce Thoman, Mission Operations Manager.*

XIII. WAMDII Vital Statistics

Capability: Measures wind and temperature by observing airglow emissions.

Description: A CCD camera views the sky through a field-widened Michelson interferometer. Values for wind and temperature are determined from measurements of phase and contrast of the fringes.

Average Power Consumption:
180 watts

Weight:
995 pounds (433.2 kilograms)

Size:
9.5 feet x 3.28 feet x 3.28 feet (2.9 meters x 1.0 meters x 1.0 meters) including baffle

Field of View:
8.5° x 11.3°

Collecting Area:
9.2 inches^2 (59.35 centimeters^2) (night)
1.9 inches^2 (12.26 centimeters^2) (day)

Data Rate:
330 kilobits per second

Observation Time Requirements:
50 hours throughout mission

Sponsor: National Research Council of Canada Ottawa, Ontario, Canada

XIV. TAPS VITAL STATISTICS

Description: Aluminum alloy structure covered with thermal blankets

Dimensions:
104 inches X 113 inches
(264.2 x 287 centimeters)

Weight:
3,000 pounds (1360.8 kilograms)

Orbital Average D.C. Power Consumption:
414 watts at 28 volts

System Accuracy:
4 arc minutes

Field-of-View Provided for WAMDII:
$\pm 20°$ in pitch, roll, or combined positions

Maximum Dimensions of Instrument TAPS Can Hold:
40 inches x 40 inches square and 166 inches long (101.6 centimeters x 101.6 centimeters x 421.64 centimeters)

Maximum Weight of Instrument TAPS Can Hold:
2,500 pounds (1134 kilograms)

Sponsor: NASA/GSFC Space Technology Division Greenbelt, Maryland

XV. Glossary

airglow — a relatively steady, faint photochemical luminescence in the upper atmosphere.

atomic oxygen — created in higher altitude regions of the upper atmosphere when oxygen molecules are split into single atoms by the influx of ultraviolet energy into the area.

aurora — luminous bands or streamers of light caused by the ejection of charged particles into the magnetic field of the Earth; sometimes visible in the night skies of the north as the aurora borealis or northern lights and in southern skies as the aurora australis.

CCD camera — charge coupled device camera, an array of minute electronic detectors of photons or particles of light.

Doppler effect — an apparent change in the frequency of waves, as sound or light, occurring when the source and observer are in motion relative to one another. The frequency increases when the source and the observer approach one another and decreases when they move apart.

DRIRU — (Dry Rotor Inertial Reference Unit) the gyro used to provide reference orientations for WAMDII.

frequency — The rate of vibration of a wave or the number of waves that pass a given point in a certain time. Frequency is inversely proportional to wavelength, so an increase in frequency means a decrease in wavelength.

GSFC — Goddard Space Flight Center, a NASA field center located in Greenbelt, Maryland.

internal atmospheric gravity waves — waves thought to be created by the effects of surface winds blowing over mountain ranges; they cause the entire atmosphere to oscillate up and down, changing the density at any one point. They also transport energy from one point to another in the atmosphere.

interferometer — an instrument that uses interference phenomena between a reference wave and an experimental wave, or between two parts of an experimental wave, to determine wave lengths, wave velocities, distances, and directions.

interferogram — a visual representation of the wavelength of a light beam; created by an interferometer.

ionized oxygen — created in the higher regions of the thermosphere when oxygen atoms gain a net electric charge by losing electrons in their outer shell; the electrons are severed due to the influx of ultraviolet light into the region.

ionosphere — a set of four electrically conductive layers of the Earth's atmosphere interspersed throughout the top of the mesosphere and the thermosphere and caused from the ionization of atmospheric gases by incident solar radiation.

JSC — Johnson Space Flight Center, a NASA field center located in Houston, Texas.

KSC — Kennedy Space Center, a NASA field center located in Cape Canaveral, Florida.

lower atmosphere — region extending 6 to 10 miles (10-16 kilometers) above the Earth's surface.

mesosphere — the part of the atmosphere from approximately 30 to 50 miles (50 to 80 km) above the Earth where temperatures can decrease to as low as -225° F (-143° C) thus making this the coldest atmospheric region.

ozone — created when short-wave ultraviolet radiation splits an ordinary two-atom oxygen molecule; the chemically active single atoms attach themselves to ordinary oxygen molecules to form three-atom molecules of ozone. This process generates an unusually high concentration of ozone in a layer that completely surrounds the Earth between the altitude of about 10 and 30 miles, protecting it from the harmful effects of ultraviolet radiation.

pitch — a term relating to the frequency of vibration of a sound. A high-pitched sound has a high frequency, a low-pitched sound, a low frequency.

POCC — Payload Operations Control Center

solar wind — a flow of plasma, high-temperature ionized gas composed of positively charged hydrogen and helium and negatively charged electrons. These opposite charges exist in such equal numbers that the gaseous medium is essentially electrically neutral. Light produced by the electrons of this plasma striking the upper atmosphere results in the aurora borealis and australis.

SPOC — Shuttle Payload of Opportunity Carrier

stratosphere — layer of the Earth's atmosphere between approximately 10 to 30 miles (16-48 kilometers) above the Earth's surface. The ozone layer is formed here due to the absorption of solar ultraviolet radiation.

TAPS — NASA's Two-Axis Pointing System (developed by GSFC) used to hold instruments in the Shuttle and position them for observation.

TDRS — NASA's Tracking and Data Relay Satellite

TSS — NASA's TAPS Support Structure which holds the Two-Axis Pointing System

thermosphere — the region between approximately 50 and 300 miles (85 and 500 kilometers) above the Earth, the highest region of the upper atmosphere.

upper atmosphere — region extending from 10 to 300 miles (16 to 480 kilometers) above the Earth's surface; comprised of the stratosphere, mesosphere, thermosphere and ionosphere.